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FINAL REPORT

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for

Laboratory Studies of
Acoustic Scattering from the Underside of Sea Ice

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**Laboratory Studies of
Acoustic Scattering from the Underside of Sea Ice**

Final Report

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The contract was a joint effort between Dr. Ken Jezek of CRREL and Dr. Tim Stanton of the University of Wisconsin-Madison. For administrative purposes we applied for separate awards to the individual institutions. Since CRREL and UW-Madison respectively are an Army and a state institution it seemed reasonable to separate the accounting. Jezek and Stanton collaborated on the research.

INTRODUCTION

Undeformed sea ice is a morphologically complicated material. The basal layer of growing sea ice (several mm thick) is composed of centimeter size patches of parallel dendrites protruding several tenths of one mm into the sea water. The patches are randomly oriented with respect to each other. Above the basal layer is liquid brine which is entrapped in submillimeter size pockets creating a very porous zone with low permeability. As the ice ages and desalinates, the porosity decreases but new features, such as drainage channels develop. Consequently, a model that describes the interaction of acoustic waves with sea ice will need to incorporate a variety of geometrical configurations that furthermore, change as the ice ages. In our work, we sought to characterize the acoustic response to sea ice and identify all important mechanisms which affect the acoustic wave.

ACCOMPLISHMENTS

We made substantial progress in this contract contributing to new understandings of the acoustic properties of sea ice. We observed important dependences of acoustic properties of sea ice upon ice type and environmental conditions which was a result of our careful measurements of ice morphology that were concurrent with the acoustic measurements. As a result of our studies, we formulated semi-empirical acoustic models of the water/ice interface that can be used as input into scattering and propagation models.

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Our accomplishments are described in detail in the publications listed below. The accomplishments can be summarized as:

1) REFLECTION. The normal incidence reflection coefficient was found to be strongly dependent upon the dendritic interface which was dependent upon the environmental conditions. We observed that the reflection coefficient ranged from approximately 0.04 to 0.4, depending upon the temperature of the ice. This order of magnitude variation was correlated with the dramatic changes in the dendritic structure of the interface when the ice transformed from rapidly growing congealation structure during cold conditions to a more static melted condition. Our work on this subject, which mostly took place at the CRREL sea ice pond at 120 and 188 kHz, was verified with the same equipment at FRAM Strait by us as well as by Francois and Garrison (APL/UW) over a broader range of frequencies.

The dependence of the reflection coefficient upon angle of incidence showed the critical angle of reflection to occur at an angle different than that predicted by using the bulk properties of sea ice. In our experiment involving 188 kHz sound, the critical angle was at 35 degrees indicating the compressional sound speed to be 2600 m/s. This value should be compared with 3500 m/s for pure ice. The reduction in sound speed is attributed to water content in the dendritic interface.

2) ATTENUATION. Measurements of attenuation over the frequency range 6 - 400 kHz demonstrated the dramatic dependence upon ice type as the attenuation in the mid-to-upper ice column was found to be negligible compared with the attenuation in the dendritic interface. For example, the attenuation in the dendritic structure at frequencies near 10 kHz is of the order 1 dB/cm while above the structure, the attenuation is roughly 1/100 of that or 1 dB/m.

3) FIELD VERIFICATION. While the majority of our work described above involved the use of the CRREL sea ice facility, some of the work has been spot checked in the field. The dramatic variation in reflection coefficient with environmental conditions was verified both by 1) us with the same equipment at the FRAM Strait and 2) Francois and Garrison (APL/UW) and 3) Wallerstedt (SAIC) with different sets of equipment, also in the arctic. Wallerstedt's measurements involved frequencies of 20 kHz.

4) COMPARISONS WITH UREA ICE. Because of some of the dramatic dependences of the acoustic properties upon ice type, we performed a parallel set of measurements with urea ice which has similar mechanical (congealation) properties but different chemical properties than that of saline ice. Our findings in the 120-400 kHz range show that the acoustic properties are essentially identical which demonstrates that the acoustic properties of sea ice that we observed are due to mechanical rather than chemical effects. This is an important distinction because in sea water, low frequency attenuation, for example, is due to chemical relaxation effects.

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5) DEVELOPMENT OF SCATTERING MODELS. The dominant scatterers in the ice are the ice keels. Between the keels are dendrites which also affect the scattering. All of these scatterers are elongated and finite in length. Furthermore, the lengthwise axis of the keels are deformed. To date, there are no adequate scattering models of rough interfaces with finite deformed elongated protuberances. We therefore embarked upon the development of models that described the scattering of sound by deformed finite length objects. Once put into the proper form, the models could be used directly in the Twersky formulation. Models developed include: straight finite fluid cylinder, straight finite elastic cylinder, deformed finite cylinder of arbitrary material composition, randomly rough finite elongated elastic objects, and deformed finite length wedges. Because of the vast complexity of the models, they were simplified in a separate article.

6) SIMPLE SCATTERER BISTATIC MEASUREMENTS (IN-PLANE). To complement our fundamental measurements involving flat interfaces, we also introduced simple discontinuities in the water/ice interface. There were two different types of discontinuities--one was a rectangular protuberance of ice to simulate to first order a keel and the other involved performing the measurements at the edge of a hole in the ice (whose side was straight) to simulate an ice lead. The bistatic acoustic scatter measurements were performed at all combinations of angles of incidence and reception down to 15 degrees grazing with a 180 degree semicircular array of transducers. The measurements demonstrated interesting large sidelobes of scattering in the non-specular direction due to interference effects in the scattering region.

PUBLICATIONS (Peer-reviewed public journals)

Stanton, T.K., K.C. Jezek, and A.J. Gow, "Acoustical Reflection and Scattering from the Underside of Laboratory Grown Sea Ice: Measurements and Predictions," J. Acoust. Soc. Am., 80, 1486-1494 (1986).

Stanton, T.K. "Sound Scattering by Cylinders of Finite Length I: Fluid Cylinders," J. Acoust. Soc. Am., 83, 55-63 (1988).

Stanton, T.K. "Sound Scattering by Cylinders of Finite Length II: Elastic Cylinders," J. Acoust. Soc. Am., 83, 64-67 (1988).

Stanton, T.K. "Sound Scattering by Cylinders of Finite Length III: Deformed Cylinders", J. Acoust. Soc. Am., 86, 691-705 (1989).

Stanton, T.K. "Simple Approximate Formulas for Backscattering of Sound by Spherical and Elongated Objects", J. Acoust. Soc. Am., 86, 1499 - 1510 (1989).

Jezek, K.C., T.K. Stanton, A.J. Gow, and M.A. Lange, "Influence of Environmental Conditions on Acoustical Properties of Sea Ice," submitted to J. Acoust. Soc. Am.

Stanton, T.K. "Sound Scattering by Randomly Rough Elongated Objects I: Means of Scattered Field," in preparation for J. Acoust. Soc. Am.

Stanton, T.K. "Sound Scattering by Randomly Rough Elongated Objects II: Fluctuations of Scattered Field, " in preparation for J. Acoust. Soc. Am.

Jezek, K.C., T.K. Stanton, A.J. Gow, "Acoustic Absorption in Saline Ice," in preparation for J. Acoust. Soc. Am.

Chu, D. and T.K. Stanton, "Sound Scattering by Deformed Wedges of Finite Length," in preparation for J. Acoust. Soc. Am.

TECHNICAL REPORTS

Jezek, K.C. "Acoustic Waves Incident on Seawater/Sea Ice Interface," CRREL Special Report No. 85-10, 6 pages.

Jezek, K.C., T.K. Stanton, A.J. Gow, and M.A. Lange, "Acoustical and Morphological Properties of Undeformed Sea Ice: Laboratory and Field Results," CRREL Report 1989, 24 pages.

PUBLISHED CONFERENCE PROCEEDINGS

Jezek, K.C., T.K. Stanton, and A.J. Gow, "Laboratory Studies of Acoustic Scattering from the Underside of Sea Ice," 1985 International Geoscience, and Remote Sensing Symposium (IGARSS '85), MP-2, part 2.

Jezek, K.C., T.K. Stanton, and A.J. Gow, "Acoustical Reflection and Scattering from the Underside of Laboratory Grown Sea Ice: Measurements and Predictions," Second Symposium on Remote Sensing in Glaciology, International Glaciological Society, Sept. 1986.

Jezek, K.C., T.K. Stanton, and A. J. Gow, "Acoustic Properties of Laboratory-grown Saline Ice," Proceedings of the Third International Symposium on Sea Ice and the Sea of Okhotsk, February 14-16, Mombetsu, Japan (1988).

Stanton, T.K. "Sound Scattering by Spherical and Elongated Objects," 13th International Congress on Acoustics, Yugoslavia (1989).

CONFERENCE PRESENTATIONS

Stanton, T.K. "Sound Scattering by Fluid Cylinders of Finite Length," J. Acoust. Soc. Am., 80 (Suppl. 1), (Fall, 1986) S127 (A).

Jezek, K.C., T.K. Stanton, A.J. Gow, "Attenuation of Sound through Laboratory Grown Saline Ice," J. Acoust. Soc. Am., 82 (Suppl. 1), S30 (Fall, 1987).

Jezek, K.C., T.K. Stanton, A.J. Gow, and M. Lange, "Laboratory and Field Measurements of Acoustic Scattering from Sea Ice," J. Acoust. Soc. Am., 84, (Suppl. 1) S123 (Fall, 1988).

Stanton, T.K. "Simple Approximate Formulas for Backscattering of Sound by Spherical and Elongated Objects," J. Acoust. Soc. Am., 84 (Suppl. 1) S219 (Fall, 1988).

Stanton, T.K. "Sound Scattering by Deformed Cylinders of Finite Length," J. Acoust. Soc. Am., 85, (Suppl. 1) S42 (Spring, 1989).